TABLE OF CONTENTS

RECORD OF REVISIONS

Rev	Date	Description	POC	OIC
0	06/28/99	Rewritten and reformatted to support LIR 220-03-01. Superseded Facilities Engineering Standards, Volume 6, Electrical, Manual Rev 15, 6/26/98.	David W. Powell, *PM-2*	Dennis McLain, *FWO-FE*
1	11/18/02	General revision and addition of endnotes. Replaces Subsections 211.3, 211.4, 214, 215, 216, 217, 244, 245.4, 245.5, 245.6, 245.7, 248, 251, 252, and 253.	David W. Powell, *FWO-SEM*	Kurt A. Beckman, *FWO-SEM*
2	05/18/05	Updated references to LANL Construction Specifications; updated references to NEC; clarified requirements for remote control wiring; added requirements for receptacles in copy rooms; modified requirements for isolated-ground receptacles; revised requirements for adjustable-frequency drives; clarified motor selection criteria; incorporated variance for replacement of self-luminous exit signs.	David W. Powell, *ENG-DECS*	Gurinder S. Grewal, *ENG-CE*

D5020 LIGHTING & BRANCH CIRCUIT WIRING

1.0 RACEWAY AND BOXES

1.1 Raceways

A. Use raceway systems to contain premises wiring systems.[1] *Metal-clad (MC) cable may be used for 15 and 20 ampere branch circuit wiring in IBC Group B Occupancies beyond the first outlet or junction box; refer to paragraph 2.4 in this Section.*

B. Size raceways considering all conductor adjustment factors required by the NEC.

C. Indicate sizes of branch circuit conduits and wireway sections on the design drawings and any changes on the record as-built drawings.[2]

D. In addition to locations required by the NEC, provide conduit sealing fittings with approved sealant at the following locations:

1. Where conduits cross the boundary of a radiological area.[3]
2. Where conduits pass between areas where air pressure differential must be maintained.[4]
3. Where conduits enter an enclosure protected by a clean agent total flooding fire suppression system.[5]

E. Design raceways penetrating radiation shielding or permanent contamination zones with sufficient bends, curvature, or shielding to prevent radiation streaming through the void.[6]

F. Use materials and installation methods described in LANL Construction Specification Section 16130, *Raceways and Boxes*.

G. Use surface metal raceway where there is a high density of receptacle outlets such as at laboratory benches and in computer server rooms. Use surface metal raceway with internal divider(s) to contain power and telecommunications distribution.

1. Use surface metal raceway in accordance with the NRTL listing for the product.
2. Use base, covers, and fittings designed by the manufacturer to be assembled together.
3. Only NRTL listed fixed multi-outlet assemblies may have the branch circuit loads calculated based on NEC, Section 220.14(H).[7]

---

[1] LANL institutional policy developed through observation and experience. Installation of wiring systems in raceway systems protects conductors and facilitates future wiring modifications. This also aligns with the New Mexico Electrical Code which prohibits non-metallic sheathed cable wiring methods in commercial and industrial occupancies.

[2] Accurate design and as-built documentation facilitates maintenance and future system modifications.

[3] The purpose of sealing raceways crossing radiological areas is to prevent the spread of contamination.

[4] Occupancies such as bio-safety labs use air pressure differentials to assure containment.

[5] NFPA 2001-2000, *Standard on Clean Agent Fire Extinguishing Systems*, paragraph 3.3: To prevent loss of [fire suppression] agent through openings to adjacent areas, openings shall be permanently sealed.

[6] DOE 6430.1A, section 1300-6.2, Shielding Design, states that straight-line penetration of shield walls shall be avoided to prevent radiation streaming.

4. Use materials and installation methods described in LANL Construction Specification Section 16130, *Raceways and Boxes*.

1.2 Flexible conduit

A. Use flexible metal conduit for connections to vibrating or moving equipment; use liquid-tight flexible metal conduit for such connections in damp or wet locations or where deteriorating agents may be present such as in some parts of mechanical rooms. Minimum length shall be 18 inches, maximum length per the NEC.[8]

B. Use materials and installation methods described in LANL Construction Specification Section 16111, *Conduit*.

1.3 Boxes

A. Provide complete system of outlet boxes, junction boxes, and pull boxes that meet requirements of the National Electrical Code and are compatible with all other related systems.

B. Coordinate locations of outlet boxes with locations and dimensions of furniture and equipment.

C. Design the branch circuit distribution system for office buildings using a modular grid of junction boxes containing the "homerun" circuits for lighting, general-power, and isolated-ground power systems to allow partition walls to be added or removed with a minimum of interruption of service to existing outlets.

D. Use the materials and installation methods described in LANL Construction Specification Section 16130, *Boxes*.

2.0 CONDUCTORS AND CABLES

2.1 Wiring Color Codes

A. Identify all branch circuit conductors (phase, grounded, and grounding conductors) using color-coding that is consistent throughout the building.[9] *For minor work[10] in existing facilities use wiring color codes that match existing color codes so long as National Electrical Code requirements for identifying grounded and grounding conductors are satisfied[11]*.

---

7 Lesson learned on LANL project. AE had calculated load for receptacles in surface metal raceway as if it were multi-outlet assembly. NEC requirement repeated for emphasis.
8 Purpose of flexible connection is to reduce noise transmission and allow equipment movement. 18 inches is about the minimum length effective for equipment adjustment or vibration isolation.
9 Color coding of phase conductors facilitates wiring system voltage identification and the correct installation of equipment requiring a specific phase sequence or phase rotation.
10 Refer to LEM Chapter 7, D5000, "Application of this Chapter" heading.
11 Refer to NEC Sections 200.6 and 250.119.

B. Refer to LANL Construction Specifications Section 16120, *Building Wire and Cable*, for the wiring color codes.

2.2 Building Wire and Cable

A. Use copper conductors that have been sized with consideration to adjustment factors for voltage drop, ambient temperature, raceway fill, harmonics, and future loading.[12]

B. Indicate on the construction or record as-built drawings the number and size of conductors in conduit runs, wireway sections, and cable tray sections.

C. Use copper conductors. Aluminum is not acceptable.[13]

D. Use minimum No. 12 AWG for branch circuit wiring.[14]

E. Design branch circuit conductors for 3 percent maximum voltage drop at full-design load.[15] Use voltage drop calculation methods outlined in Chapter 3 of IEEE Std 141.

F. For isolated ground branch circuits and branch circuits serving high-harmonic loads such as personal computers:

1. Provide a dedicated grounded (neutral) conductor for each branch circuit.[16]
2. Select branch circuit conductors considering the neutral as a current-carrying conductor.[17]
3. Refer to “System Characteristics” in section D5010 for isolated ground power system requirements.

G. In areas where the total integrated gamma dose for the useful life of the facility is calculated to be 10^6 rads or greater, such as hot cells, provide conductor insulation such as cross-linked copolymer, polyvinyl chloride, or polyethylene. Radiation doses will be specified in the project design criteria.[18]

H. Use materials and installation methods described in LANL Construction Specifications Section 16120, *Building Wire and Cable*.

2.3 Remote Control Wiring

A. Comply with NEC Article 725.

---

[12] Adjustments for raceway fill, ambient temperature, and harmonics are required in NEC Article 310.15.

[13] The New Mexico Electrical Code prohibits the use of aluminum conductors smaller than No. 2; this prohibition is extended to all conductor sizes at LANL.

[14] The use of minimum 12 AWG on branch circuits limits voltage drop.

[15] AHSRAE/IESNA Standard 90.1-2004 requires the stated voltage drop design criteria in paragraph 8.4.1.2.

[16] IEEE Std 1100-1999, *IEEE Recommended Practice for Powering and Grounding Electronic Equipment* (Emerald Book), in paragraphs 8.3.2.3.1 and 8.3.2.3.2, recommends a dedicated grounded conductor (neutral) for each branch circuit.

[17] Refer to NEC section 310.15(B)(4)(c).

[18] Gamma radiation can cause deterioration of the physical and electrical properties of polymers used in conductor insulation materials. Refer to IEEE 1205, *IEEE Guide for Assessing, Monitoring, and Mitigating Aging Effects*.

1. Install life safety, safety-class, safety-significant, and other critical remote control wiring in conduit systems.
2. *Non-critical Class 2 and Class 3 remote control wiring, such as room thermostat wiring in office buildings, may be installed exposed above lift-out ceilings.*

B. Class 1, line voltage (120V), and safety-related remote control wiring:

1. Use stranded copper conductors with 600V THHN/THWN insulation.
2. Terminate wiring using crimp-on ring tongue or pin-type lugs as appropriate for the terminal.[19]

C. Class 2 and Class 3 remote control wiring:

1. Use stranded multi-conductor cable; use twisted-pair shielded cable for circuits carrying analog signals or digital data.
2. Install Class 2 and Class 3 remote control wiring in separate raceways from line voltage and Class 1 remote control wiring.
3. Terminate Class 2 and Class 3 remote control conductors directly in terminal blocks.
4. Ground cable shields at the controller end; insulate cable shield at the field device end.

D. Install remote control wiring without splice or tap from wiring terminal to wiring terminal.

E. Label remote control wiring using wire markers at both ends with complete “from” and “to” terminal information. Identify the panel, terminal block, and terminal number. Use materials and installation methods described in LANL Construction Specifications Section 16075, *Electrical Identification*.

2.4 Metal-Clad Cable

A. *In IBC Group B Occupancies, metal-clad cable (Type MC) may be used for 15- and 20-ampere branch circuit wiring systems beyond the first outlet or junction box.*[20, 21, 22] Use conduit for the “homerun” from the first outlet or junction box to the branch circuit panelboard.[23]

---

19 Crimp-on lugs increase the reliability of terminations for stranded control conductors.

20 IBC group B includes offices, computer rooms, and light laboratories. For these types of occupancies, Type MC may be a more cost-effective wiring method than conventional wire in conduit.

21 A cost analysis using office space meeting the lighting and receptacle requirements of this Chapter shows that the metal clad cable wiring method saves about $1.65 per square foot compared to the wire in EMT wiring method. Costs used are from the 2000 Means Electrical Cost Data Book; these costs are conservative because LANL costs are 2 or 3 times national averages.

22 IEEE Std 1100-1999, IEEE Recommended Practice for Powering and Grounding Electronic Equipment, in paragraph 8.4.11, discusses the advantages of metal-clad cable for branch circuits serving electronic equipment.

23 Use of conduit for the branch circuit homeruns will facilitate the future addition of branch circuits from the panelboard to the vicinity of new loads.

B. Use of Type MC cable is limited to interior, dry locations in Group B occupancies where it will be concealed above suspended ceilings, in dry-wall partitions, in equipment enclosures, or below raised floors.[24] Type MC cables may be installed exposed in dedicated electrical rooms and mechanical rooms if not be exposed to physical damage or deteriorating agents.

C. Use 12 AWG minimum conductor size.

1. Use larger conductor sizes as required to limit voltage drop as required in this Section.
2. Use larger conductor sizes to adjust allowable ampacity if there are more than 3 current-carrying conductors in a cable. Refer to NEC Article 310.15 for adjustment factors.[25]

D. Provide cable with color-coded conductor insulation as described in 2.1 Wiring Color Codes.

E. For isolated ground power circuits use cable with a separate grounded conductor for each phase conductor. Uniquely color-code each grounded conductor to associate it to the corresponding phase conductor.

F. Use materials and installation methods described in LANL Construction Specifications Section 16120, *Building Wire and Cable*.

2.5 Flexible Cord and Cable

A. Use flexible cords, cables, and their associated fittings that are UL approved and suitable for the conditions of use.[26] Consider temperature, operating voltage, and exposure to moisture, oils, chemicals, sunlight, ozone, and physical abrasion in selecting cords and cables.

B. Use flexible cords and cable only for the following applications:[27]

1. Pendant receptacles for 15, 20 or 30 amp, 120, 120/240 or 208Y/120V circuits.
2. Exposed connections for lighting fixtures.
3. Connections of portable lamps and appliances using an attachment plug and energized from a receptacle outlet.
4. Connections of stationary equipment to facilitate their frequent interchange using an attachment plug and energized from a receptacle outlet that is mounted on the building or structure.
5. Connection of appliances where the fastening means and mechanical connections are specifically designed to permit ready removal for maintenance or repair and the appliance is intended or identified for flexible cord connection using an attachment plug and energized from a receptacle outlet.
6. Connection of moving parts.

---

24 NEC Article 330 permits MC cable to be installed exposed; however LANL institutional policy is to conceal this wiring method in finished spaces.

25 NEC Article 310.15 ampacity adjustments apply to conductors in MC cable.

26 Refer to LEM Chapter 7, D5000, “NRTL Listing” heading, which requires the use of listed materials in accordance with their intended use.

27 Uses permitted are based on NEC Section 400.7.

7. For temporary wiring as permitted by the NEC during construction, remodeling, repairs, emergencies, tests, experiments, and developmental work. Remove temporary wiring immediately upon completion of the construction, remodeling, repair, emergencies, tests, experiments, or developmental work for which it was installed.

C. Use flexible cords and cables containing a green insulated equipment-grounding conductor to provide an effective ground-fault current path.[28]

D. Use flexible cords and cables only in continuous lengths without splices or taps.[29]

E. Flexible cords and cables used at LANL shall be limited to the “hard service” cords, “junior hard service” cords, and “portable power” cables listed in NEC Table 400.4 except where the cord or cable is supplied as part of an NRTL listed appliance.[30]

3.0 WIRING DEVICES

3.1 Receptacle Outlets

A. Provide receptacle outlets at locations required and in sufficient density to minimize or eliminate the use of extension cords, relocatable power taps, and outlet strips.[31]

B. Show receptacle outlets on the design drawings and any changes on the record as-built drawings.

C. Provide 120-volt, 15- or 20-ampere[32] general-purpose duplex receptacle outlets connected to 20-ampere[33] circuits at the locations described below, at locations required by the NEC, and at locations dictated by the User’s functional and operational requirements. Design distribution system using a unit load of 180 VA per general-purpose receptacle strap.[34]

1. Hard wall enclosed offices, conference rooms, copy rooms, laboratories, and similar spaces: One outlet on each wall plus additional outlets so no point measured horizontally in any wall space is more than 6 ft from a general-purpose receptacle outlet.[35]
2. Open-office workstations: At least two outlets plus additional outlets so no point measured horizontally in any wall panel space where equipment may be located is more than 6 ft from a general-purpose receptacle outlet.

---

28 An effective ground-fault current path is required in NEC Article 250 to limit the voltage to ground on all electrical equipment.

29 Requirement for no splices or taps in portable cords is expanded from NEC Article 400.9 to improve personnel safety and reduce fire hazards.

30 Portable power cords and cables are expected to be subjected to hard usage in harsh environments.

31 Reduction of the use of extension cords, power strips, and relocatable power tabs will reduce fire and electrocution hazards and will improve power quality.

32 The NEC permits multiple 15-ampere receptacles to be served by a 20-ampere circuit. This provides adequate service and permits the use less costly 15-ampere wiring devices.

33 The use of 20-ampere general-purpose branch circuits is standard commercial and industrial design practice.

34 180 VA per receptacle strap is the minimum load for receptacle outlets permitted by NEC Article 220. Use of this load permits the use of the receptacle load demand factors in NEC Section 220.13.

35 Receptacle spacing is based on the 6-ft cords supplied with most electrical equipment used in offices. Adequate accessible receptacle outlets will reduce or eliminate the need for extension cords and portable outlet strips.

3. Laboratory countertops: At least one outlet for each 3 ft of countertop.[36]
4. Kitchens and break rooms: At least one outlet on each wall where not used for counters.
5. Equipment rooms: At least one outlet plus additional receptacle outlets so all equipment that may require maintenance is within 25 ft of a receptacle.[37] *See requirement below for GFCI receptacles in mechanical equipment rooms.*
6. Corridors: 20-ampere receptacle outlets on dedicated circuit(s) for custodial use located so no point on any corridor floor is more than 25 ft from an outlet.[38]
7. Copy rooms: One outlet on each wall plus additional outlets so no point measured horizontally in any wall space is more than 6 ft from a general-purpose receptacle outlet. At least one outlet for each 3 ft of countertop or fraction thereof for small office equipment such as FAX machines and printers. At least one 20 ampere receptacle on an individual circuit for a copy machine. *Some copy rooms may have high-capacity printers requiring higher-capacity circuits.*

D. Provide 120-volt, 15 or 20-ampere, double-duplex[39] PC receptacle outlets connected to dedicated circuits[40] at the locations described below and at locations dictated by the User's functional and operational requirements to serve PCs, monitors, and printers:

- Hard wall enclosed offices: At least two outlets located on opposite walls.[41]
- Open-office workstations or cubicles: At least one outlet.
- Laboratories: At least one outlet.
- Conference rooms: At least one outlet located at the front of the room. At least one floor outlet located centered under the conference table for audio-visual and teleconferencing equipment.
- Mechanical rooms: At least one outlet in each mechanical room for building automation system equipment.

1. Unless the User has more definitive requirements, use the unit loads in Figure D5020-2 for double-duplex receptacle outlets in office and laboratory occupancies.

---

36 3 ft spacing of receptacles at lab workbenches provides a reasonable degree of capacity for general bench-top laboratory equipment.

37 At least one receptacle outlet is required so cords do not pass through doorways. Locating receptacles within 25 ft of equipment requiring maintenance will keep extension cord use within reasonable limits.

38 Power cords on commercial vacuum cleaners are typically 30 ft or longer. The 25-ft requirement is to prevent excessive mechanical strain on plugs and receptacles. The 20 amp receptacles are to accommodate floor buffers and carpet cleaning equipment.

39 A double-duplex receptacle outlet provides a plug connection for the computer, monitor, speaker amplifier, and printer that comprise a typical PC station.

40 IEEE Std 1100-1999 in paragraph 8.3.2.3.1 recommends that office work stations have separate, dedicated branch circuiting and receptacles for electronic equipment and another separate receptacle circuit for convenience loads or high impact loads such as electric heaters, hand tools, and copy machines.

41 Many LANL offices have more than one computer station.

Figure D5020-2 PC Workstation Loads[42]

PC Workstation Equipment	Average Measured Current (Amps)	Unit Load (Volt-Amps)	Feeder/Service Demand Factor
Computer	3.00	360	100%
Monitor	1.72	206	100%
Printer	3.75	450	100%
Load per double-duplex receptacle		1016	100%

2. *For outlets serving secure office PC stations operating in the "KVM" mode the branch circuit load per double-duplex receptacle may be reduced to 566 VA.*

3. For computer or instrument circuit receptacles not connected to SPD protected circuits, use UL 1449 (Standard for Safety for Transient Voltage Surge Suppressors) listed, 125 volt, 15- or 20-ampere, surge suppression type duplex receptacles.[43]

E. Provide 120-volt, 15 or 20-ampere duplex ground-fault circuit-interrupter (GFCI) type receptacle outlets[44] at the locations described below and at locations dictated by the User's functional and operational requirements. Design distribution system using a unit load of 180 VA per GFCI receptacle strap.

1. Outdoor locations, including roofs: At least one outlet within 25 ft of mechanical equipment that may require maintenance.[45, 46]

2. Outdoor locations: At least one outlet within 6 feet of each personnel and vehicle entrance plus additional outlets so no point measured horizontally on the building perimeter is more than 80 ft from a receptacle outlet.[47]

3. Laboratory and experiment areas: Any outlets that are located within 6 feet of a sink.[48] (At least one receptacle outlet in each laboratory must be non-GFCI.[49])

4. Laboratory, experiment, battery, and chemical areas: Any outlets that are located within 6 feet of an emergency shower/eyewash station.

5. Kitchen/break areas: At least two outlets serving the countertop area(s).[50] Provide at least one outlet for each countertop space that is 12 inches or wider.[51] Provide receptacle and dedicated circuit for each vending machine. Design distribution system using a unit load of 1500 VA per circuit.[52]

---

42 Based on survey and measurement of 89 computer workstations in PM Division during the summer of 1999.
43 Paragraph 2.5.2 in D5010 establishes 30 outlets as the point for providing a panel-mounted TVSS; for less than 30 outlets, TVS-type receptacles are a more economical alternative.
44 Ground fault receptacles are usually more economical and more reliable than ground fault circuit breakers, especially on long branch circuits.
45 Uniform Mechanical Code, 2000 Edition, paragraph 309.0 requires a receptacle outlet within 25 ft of mechanical equipment.
46 NEC section 210.8(B) requires GFCI protected receptacle outlets.
47 80-ft receptacle spacing allows a 100-ft cord to reach all points within 60 ft of the building exterior.
48 Requirement for GFCI receptacles is based on increased electrocution exposure in a potentially wet area.
49 Non-GFCI receptacle is for critical equipment such as laboratory refrigerators that must not unintentionally be shut off.
50 NEC Section 210.8(B) requires GFCI receptacles in non-dwelling kitchens.
51 NEC Section 210.52(C) is extended to non-dwelling occupancies.
52 Unit load for receptacle outlets in kitchen and break areas is to adequately serve User-supplied vending machines, coffee makers and microwave ovens.

6. Bathroom and shower areas: At least one above-counter outlet within 36 inches of each lavatory bowl.[53] At least one below lavatory counter to serve power supplies for proximity-sensing electronic faucets and flush valves.
7. Mechanical equipment rooms: At least one outlet plus additional outlets so all equipment that may require maintenance is within 25 ft of a receptacle.[45]
8. Janitor closets. At least one outlet.[54]
9. Static-grounded areas: Provide outlets to meet the User's functional and operational requirements.[55]

F. Provide 120-volt, 15 or 20-ampere isolated ground type receptacle outlets served by isolated-ground circuits for equipment that is sensitive to common-mode noise including:

1. Equipment in an information technology equipment room as defined in NEC Article 645 and NFPA 75.
2. Equipment in telecommunications server equipment rooms and RED server equipment rooms as described in ESM Chapter 7 Section D5030.
3. Other locations as dictated by the User's functional and operational requirements.

G. Coordinate receptacle locations with furniture and equipment layout so receptacle outlets will be accessible.

1. In common areas (conference rooms, break rooms, etc.) install receptacle (and telecommunications) outlets with center 18 inches above the finished floor.[56] Locate outlets to comply with Americans with Disabilities Act Accessibility Guidelines (ADAAG), 28 CFR Part 36, Appendix A.
2. Locate wall mounted receptacle (and telecommunications) outlets in hard wall-enclosed offices with center 7" above the finished floor (immediately above the cove base).[57, 58] Coordinate locations of receptacle outlets with modular furniture and associated hangers to assure that receptacles will be accessible.[59]
3. Coordinate mounting height of receptacle outlets at lab benches and counters with architectural details. The maximum height to meet ADAAG requirements is 44 inches.[56]

H. Group power and communications outlets so a symmetrical appearance results.

I. Use single receptacles for drinking water fountains.[60]

J. For 20, 30, 60, and 100-ampere heavy-duty, splash proof, or watertight receptacle outlets, use pin and sleeve type receptacles that are listed to UL Standard 498 and conform to IEC Standard 309. For a 480 volt or 480Y/277 volt receptacle that is out of sight or more than 50

---

53 NEC Section 210.52(D) is extended to non-dwelling occupancies.
54 Outlet to serve battery chargers for battery-powered janitorial equipment.
55 The DOE Explosives Safety Manual, paragraph 7.8, recommends GFCI receptacles in static grounded areas.
56 Height complies with *ADA Accessibility Guidelines for Buildings and Facilities* (ADAAG), (28CFR, Ch 1, Part 36, App A) available at http://www.access-board.gov/adaag/html/adaag.htm.
57 Office spaces with special ADAAG accommodations will be provided on an as-needed basis.
58 The 7" center mounting height will allow the outlet device plate to be completely above a 4" cove base and below furniture "modesty panels" that are typically 9-1/4" AFF.
59 Lesson learned form LANL construction projects.
60 This is to prevent overloading EWC circuits by vacuum cleaners and buffers.

ft from a lockable circuit disconnect, use a receptacle with an interlocked circuit disconnect to prevent insertion or removal of a plug with the receptacle energized.[61]

K. Connect receptacle outlets to branch circuits as follows:

1. Connect a maximum of eight general-purpose duplex receptacles per 20-amp circuit.[62]
2. Connect a maximum of two double duplex PC receptacles per 20-amp circuit.[63] Install a dedicated grounded conductor for each circuit (no multi-wire branch circuits). Install a dedicated equipment-grounding conductor for each circuit. Install branch circuits to PC receptacles in separate raceways from general-purpose receptacles.[64]

L. Test each 15- and 20-ampere, 120-volt receptacle using a UL listed tester that impresses a momentary load of at least 15 amperes on the branch circuit conductors and the equipment-grounding path.[65]

M. Use materials and installation methods described in LANL Construction Specifications Section 16140 - *Wiring Devices*.

3.2 Receptacle Plates

A. For flush mounted receptacles use brushed 302/304 alloy stainless steel plates.[66]

B. For surface mounted receptacles use galvanized steel, 4-inch square covers.

C. For flush mounted interior receptacles connected to special power systems to serve computers and other equipment processing secure information, use red colored smooth plastic plates.[67]

D. Use materials and installation methods described in LANL Construction Specifications Section 16140 - *Wiring Devices*.

4.0 WIRING CONNECTIONS

4.1 General

A. Make power, control, and interlock connections to electrically operated equipment in accordance with the NEC and the equipment manufacturer’s instructions.

B. Use materials and methods described in Sections D5000, D5010, and D5020 of the LEM and suitable for the installation location and environment.

---

[61] IEC pin and sleeve receptacles provide more positive voltage class indication than NEMA configured devices. They can be safely plugged and un-plugged at full rated voltage and current.

[62] Limit of eight general-purpose receptacles per circuit aligns with the 1999 New Mexico Electrical Code.

[63] Two double duplex receptacle outlets would be capable of serving two PC stations with a total branch circuit load of 2032 VA or 16.93 amps. This loading of a 20-amp circuit is permissible because the PC station load is not continuous.

[64] Recommended practice from §8.3.2.3.1 in IEEE Std 1100-1999.

[65] The common neon lamp receptacle testers can give false indications of proper grounding. Testers that impose a load on the ground path are more likely to identify faulty grounds or incorrect receptacle connections.

[66] Stainless steel plates provide greater durability than other materials.

[67] This method cost-effectively identifies outlets intended for “RED” (secure) processing equipment.

C. Install receptacle outlets, disconnect switches, motor controllers, and control devices to complete the equipment wiring connections.

D. Provide dedicated power circuits for building automation systems and related control system components.

E. Some specialized, non-domestic, and possibly non-NRTL-listed laboratory equipment will require power with different characteristics (voltage, frequency, etc.) than that available in the facility. Provide the power conversion or transformation apparatus required for safe and proper operation of the equipment. Non-NRTL-listed laboratory equipment, special power conversion apparatus (frequency converters, buck-boost transformers, etc.), and their installation must be approved by the LANL electrical AHJ.[68]

F. Show locations, sizes, and configurations of equipment connections on the design drawings. Record changes to locations, sizes, and configurations of equipment connections in the project record documents.

5.0 MOTORS AND MOTOR CONTROLLERS

5.1 Motor Controllers

A. Provide an NRTL listed, NEMA rated controller for each three-phase motor load that does not have an integral controller or is not controlled from a motor control center. *Starters and related control devices in factory assembled control systems may be IEC type with IEC 947-4-1 type 2 coordination.*

B. Apply motor controller types as follows to limit voltage dips to acceptable levels:

1. Full-voltage starting may be used for motors with locked rotor kVA not exceeding 25 percent of the utility supply transformer(s) base (self-cooled) kVA rating.[69]

2. Use reduced voltage starting (electro-mechanical, solid-state “soft start”, or variable speed drive) for motors with locked rotor kVA exceeding 25 percent of the utility supply transformer(s) base (self-cooled) kVA rating.

3. If a motor will be served by a standby or emergency power system, use reduced voltage starting (electro-mechanical, solid-state, or variable speed drive) if the locked rotor kVA exceeds 10 percent of the generator kVA rating.

C. Provide motor controllers having a UL 508 short circuit withstand rating that exceeds the fault current available at the controller line terminals.[70]

D. Use a control voltage of 120V or less.[71] Refer to “Remote Control Wiring” in Section D5020 for additional requirements.

---

68 Refer to paragraph 5.5 in LIR402-600-01.1, *Electrical Safety*.
69 Criteria for motor starting from Section 3.9.1 of IEEE Std 141-1993.
70 Required by NEC Section 110.9.
71 Use of 120V control power provides a greater degree of safety than line voltage control power. Some equipment manufacturers use much lower voltage control power.

E. Provide LED type indicator lights on the front of each magnetic controller.[72] Indicating lights shall be color-coded and labeled to clearly identify the operational mode of the equipment or system. *Refer to drawing ST-D5020-1 for pilot light connections. Pilot lights in integrated motor controller interface modules may be used as supplied.* For discrete pilot lights use the following indicator light color code:[73]

1. RED (Stop/Danger/Hazard) denotes a system or component that is energized, running, or closed.

2. GREEN (Go/Normal/Safe) denotes a system or component that is de-energized, stopped (not running), or open.

3. AMBER (Caution/Standby/Pending Trouble) denotes a fault condition.

Note that other pilot light color codes are used on control panels for industrial machinery built to NFPA 79 or in process systems that are built to ISA Standard 5.5.

F. Provide start-stop switch function on the front of each magnetic controller not connected to automatic controls. Arrange control circuit to include emergency stop functions, such as fire alarm interlocks.

G. Provide HAND-OFF-AUTO (H-O-A) selector switch or ON-OFF-AUTO switch function on the front of each magnetic controller connected to automatic controls. *Refer to drawing ST-D5020-1 for selector switch connections.* Arrange control circuit to accomplish the following operating sequences:

1. With the selector switch in the HAND or ON position the motor runs. Emergency stop functions, such as fire alarm interlocks, are in effect.

2. With the selector switch in the AUTO position the motor is controlled by the external automatic control system. Emergency stop functions, such as fire alarm interlocks, remain in effect.

3. With the selector switch in the OFF position the motor is stopped, and the external automatic control system will not control the motor.

H. *Some applications may warrant a highly visible EMERGENCY OFF mushroom head stop button on the face of the controller. Emergency off switch function should be a maintained switch action with either turn-to-release, pull to release, or key-unlock release to assure that automatic controls will not re-start the motor.*

I. For three phase motor starters serving low-voltage motors with full load current less than 100 amperes, provide solid state motor starter overloads with the following characteristics:

1. NEMA Class 20 overload trip characteristic (unless motor/load combination dictates a need for a Class 10 start time characteristic).

---

[72] LED pilot lights are more reliable and require less maintenance than incandescent pilot lights.

[73] Pilot light color codes of RED for “running” and GREEN for “stopped” or “off” are commonly used in motor controllers for building systems.

2. Field selectable overload trip current.

3. Ambient temperature insensitive.

4. Phase-loss and phase-unbalance protection.

5. Manual reset after time delay.

6. Integral current transformers.

J. For motor starters serving low-voltage motors with full load current from 100 to 300 amperes provide solid state motor overload protection with the following characteristics:

1. NEMA Class 20 overload trip characteristic (unless motor/load combination dictates a need for Class 10 or Class 30 start time characteristic).

2. Field selectable/adjustable overload trip current.

3. Phase unbalance protection and phase loss protection.

4. Manual or electric reset after time delay.

5. Current sensing using external current transformers with 5 amp secondary.

K. For motor starters serving low-voltage motors with full load current over 300 amperes, or medium-voltage motors, provide a solid state motor protective relay with the following characteristics:

1. Thermal overload protection; IEEE C37.2 function number 49

2. Locked rotor protection; IEEE C37.2 function number 51.

3. Phase fault protection; IEEE C37.2 function number 50.

4. Ground fault protection; IEEE C37.2 function number 50G/51G

5. Current unbalance protection; IEEE C37.2 function number 46.

6. Load jam protection; IEEE C37.2 function number 48.

7. Load loss protection; IEEE C37.2 function number 37.

8. Stator winding temperature with RTDs, alarm or trip; IEEE C37.2 function number 49.

9. Motor bearing temperature with RTDs, alarm or trip; IEEE C37.2 function number 38.

10. Starts per hour limit; IEEE C37.2 function number 66.

11. Selectable manual or automatic reset.

12. Display of motor phase current and ground current.

13. Display of number of starts and run time.

14. Display of trip type.

15. Current sensing using external current transformers with 5 amp secondary for phase currents and zero sequence ground fault.

L. Except for packaged equipment with integral controllers, do not locate motor controllers above ceilings.[74]

M. Position packaged equipment to obtain the NEC required clearances to integral control equipment.[75]

N. Use material and installation methods described in LANL Construction Specifications Section 16420, *Enclosed Controllers*.

5.2 Motor Control Centers

A. Use motor control centers where the total installed cost will be less than that for individual combination starters. *This is usually when there are more than three 480V motor loads that require controllers.* Avoid using motor control centers for distribution switchgear; switchboards and panelboards are more economical. Where possible, locate motor control centers in mechanical rooms containing the motors served.

B. Provide motor control centers with bus short circuit rating that exceeds the available fault current.

C. Provide motor control centers with main bus capable of 20% future load growth. Provide 10% spare starters (not less than one) and 10% spare spaces (not less than one) in each motor control center for future use.[76]

D. Refer to LANL Facility Construction Specifications Section [16482][16443], *Motor Control Center* for material and installation requirements.

5.3 Adjustable Frequency AC Controllers

A. In addition to the requirements for magnetic combination type starters, use the following requirements and guidance for selecting adjustable frequency AC controllers (AFCs) serving induction motors for fans and centrifugal pumps:

1. Use configured AFCs each consisting of an integrated assembly with externally operated disconnect device, current-limiting fuses, line input reactor, power converter, cooling fans, operator interface, control system interface, control power transformer, and a suitable enclosure.

---

[74] Controllers located in crowded ceiling spaces have often lacked adequate working space to meet requirements in NEC Article 110.

[75] Motor controllers are likely to require testing or inspection while energized; therefore, NEC section 110.26(A) must be satisfied.

[76] The combination of spare starters and spaces is intended to fulfill the requirement for future 20% growth.

2. Interface AFCs with the building automation system using ANSI/ASHRAE Standard 135, ISO 16484-5 approved BACnet compatible communications.

3. Interface AFCs with process systems using analog inputs with 0-20 mA, 4-20 mA or 0-4 V, 0-8 V, and 0-10 V parameters and 0-10 V output signal proportional to speed or load as required to interface with control system

4. De-rate AFC capacity to 7500 ft altitude, 3% to 5% high supply voltage (typical), and high carrier frequency. *These factors often mean that VFD application capability is as low as 75% of drive rated current.*

5. Provide the AFCs serving life safety, safety class, and mission critical loads with 3-contactor isolation and bypass system; refer to Electrical Drawing ST-D5020-1 for example control diagram.

6. Refer to LANL Specification Section 16269 *Adjustable Frequency AC Controllers* for material and installation requirements.

B. Locate PWM-type AFCs as close as practical to the motors they serve. If the distance from the AFC to the motor must exceed 100 ft provide line reactors or other means to limit high frequency voltage at the motor terminals.

C. Avoid installing a safety disconnect switch between AFCs and motors. If a safety disconnect must be installed, interlock the controller run-permissive circuit using an auxiliary switch in the disconnect.

D. In addition to the harmonic mitigating features specified for individual AFCs, provide additional harmonic mitigating distribution system components as required to limit harmonic currents and voltages at the point of common coupling to comply with IEEE 519-1992, *IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems.*

1. If the total connected kVA of AFCs exceeds 15 percent of the self-cooled kVA rating of the facility service transformer submit analysis of harmonic distortion at the point of common coupling (PCC).

2. The PCC for voltage distortion shall be at the secondary of the utilization voltage service transformers.

3. The PCC for current distortion shall be at the primary of the utilization voltage service transformers.

4. Use analysis procedures outlined in IEEE 519-1992; assume that all connected AFCs are operating at 80% speed.

5.4 Manual Starters

A. Use 120 VAC single-phase manual switches for starting single- phase fractional horsepower motors where automatic or remote control is not required. (Use magnetic starters for all three-phase motors and for single-phase motors requiring automatic or remote control.)

B. Provide manual switch starters with thermal overload protection for single-phase motors not having internal automatic thermal overload protection or impedance protection.

C. Provide manual motor starters with means for padlocking in the OFF position.

D. Provide each manual motor starter with an LED type red running pilot light.

5.5 Motor Disconnecting Means

A. Install disconnecting means within sight of each motor and its driven equipment.[77] *The motor controller disconnecting means can serve as the motor disconnecting means if it is within sight of the motor and its driven equipment.*

B. For three-phase motors use heavy-duty type, NRTL listed, horsepower rated non-fused safety switches that meet NEMA KS 1. Some HVAC equipment manufacturers require dual-element fuses as overcurrent protection for their rooftop units; use fused safety switches with dual-element Class RK1 fuses for such equipment.

C. For single-phase motors use NRTL listed, horsepower rated toggle switches.

D. Provide the appropriate NEMA enclosure type for the environment.

E. Provide permanently installed padlocking provision for each motor disconnecting means.[78]

F. Locate disconnecting means at either the controller or the motor to be readily accessible.[79]

G. Refer to LANL Specification Section 16410 *Safety Switches and Enclosed Circuit Breakers* for material and installation requirements.

5.6 Motor Connections

Use NRTL-listed motor lead splicing kits for insulating and sealing bolted pigtail and in-line connections in terminal boxes of motors rated 1 hp and larger. Provide splicing kits that include a 1 kV dielectric rated sleeve with thick walls to resist abrasion and puncture.[80]

---

77 Refer to NEC Section 430.102(B). Since few LANL facilities are “industrial installations,” condition (b) in the Exception to Section 430.102(B) can’t be used for most LANL facilities.

78 Permanently installed padlocking provisions will facilitate compliance with LANL lock-out/tag-out requirements.

79 Requirement in NEC section 430.107 repeated for emphasis.

80 Lesson learned from cooling tower replacement project at TA-53. Motor lead splices insulated with vinyl electrical tape failed after a short time due to abrasion of the tape.

5.7 Motors

A. Use NEMA Premium labeled[81] energy efficient motors for new installations and for replacements of motors that have failed. Use motors with minimum efficiencies that comply with Table D5020-3 and are measured according to NEMA Standard MG1 and IEEE Std 112, test method B. Motor nameplates shall contain efficiency labeling per NEMA Standard MG1-12.53b for full-load efficiency with indicated maximum and minimum expected efficiency. Motor nameplate minimum efficiency shall meet or exceed the minimum values in Table D5020-3.

Table 5020-3 Minimum Motor Efficiency

NOMINAL FULL-LOAD EFFICIENCY						
MOTOR HP	NUMBER OF POLES / SYNCHRONOUS SPEED, RPM					
	ODP MOTORS			TEFC MOTORS		
	2 3600	4 1800	6 1200	2 3600	4 1800	6 1200
1	77.0	85.5	82.5	77.0	85.5	82.5
1.5	84.0	86.5	86.5	84.0	86.5	87.5
2	85.5	86.5	87.5	85.5	86.5	88.5
3	85.5	89.5	88.5	86.5	89.5	89.5
5	86.5	89.5	89.5	88.5	89.5	89.5
7.5	88.5	91.0	90.2	89.5	91.7	91.0
10	89.5	91.7	91.7	90.2	91.7	91.0
15	90.2	93.0	91.7	91.0	92.4	91.7
20	91.0	93.0	92.4	91.0	93.0	91.7
25	91.7	93.6	93.0	91.7	93.6	93.0
30	91.7	94.1	93.6	91.7	93.6	93.0
40	92.4	94.1	94.1	92.4	94.1	94.1
50	93.0	94.5	94.1	93.0	94.5	94.1
60	93.6	95.0	94.5	93.6	95.0	94.5
75	93.6	95.0	94.5	93.6	95.4	94.5
100	93.6	95.4	95.0	94.1	95.4	95.0
125	94.1	95.4	95.0	95.0	95.4	95.0
150	94.1	95.8	95.4	95.0	95.8	95.8
200	95.0	95.8	95.4	95.4	96.2	95.8
250	95.0	95.8	95.4	95.8	96.2	95.8
300	95.4	95.8	95.4	95.8	96.2	95.8
350	95.4	95.8	95.4	95.8	96.2	95.8
400	95.8	95.8	95.8	95.8	96.2	95.8
450	95.8	96.2	96.2	95.8	96.2	95.8
500	95.8	96.2	96.2	95.8	96.2	95.8

[81] The NEMA Premium label program is sponsored by the National Electrical Manufacturers Association (NEMA) and endorsed by the Consortium for Energy Efficiency (CEE). Executive Order 13123 and FAR part 23 direct agencies to purchase products in the upper 25% of energy efficiency. Refer to DOE's Federal Energy Management Program information on NEMA Premium label motors at http://www.eren.doe.gov/femp/procurement/pdfs/motor.pdf.

B. Select motor rated voltage to economically serve the load, to match building system voltage(s), and to limit voltage dip when starting the motor.[82] *Use the following as guidance in selecting motor rated voltages:*

1. *200V, 230V, or 460V, 3-phase, 60 Hz for motors 1 HP and larger; match building secondary service voltage.*

2. *460V, 3-phase for motors 25 HP and larger.*

3. *4160V, 3-phase for motors 500 HP and larger.*

4. *120V, single phase, 60 Hertz for motors smaller than 1 HP.*

C. Do not select motors to operate continuously above rated load in the service factor area (e.g. with a service factor greater than 1.0).[83]

D. De-rate motors for operation at 7500 ft. altitude in accordance with Table 5020-4 taking into consideration the ambient temperature of the motor environment. Select motor based on 104 degrees F ambient temperature unless motor is in a moving air stream when operating.

Table 5020-4 Motor Selection Table[84]

Motor Nameplate (hp)	Maximum Motor Shaft Load[e] (bhp)					
	Ambient Temperature[a, b, c] (deg F)					
	81.1	85	90	95	100	104[d]
1	1.00	0.98	0.95	0.92	0.89	0.87
1.5	1.50	1.47	1.43	1.38	1.34	1.31
2	2.00	1.96	1.90	1.85	1.79	1.75
3	3.00	2.93	2.85	2.77	2.68	2.62
5	5.00	4.89	4.75	4.61	4.47	4.36
7.5	7.50	7.34	7.13	6.92	6.71	6.55
10	10.0	9.78	9.51	9.23	8.95	8.73
15	15.0	14.7	14.3	13.8	13.4	13.1
20	20.0	19.6	19.0	18.5	17.9	17.5
25	25.0	24.5	23.8	23.1	22.4	21.8

82 Refer to Chapter 3 of IEEE Std 141-1993.

83 Service factor is an indication of how much overload a motor can withstand when operating normally within the correct voltage tolerances. For example, the standard SF for open drip-proof (ODP) motors is 1.15. This means that a 10-hp motor with a 1.15 SF could provide 11.5 hp when required for short-term use. In general, it's not a good practice to size motors to operate continuously above rated load in the service factor area. Motors may not provide adequate starting and pull-out torques, and incorrect starter/overload sizing is possible.

84 Motor selection table is based on NEMA MG 1-12 with the following assumptions:

a. Motors will not be operated beyond a service factor of 1.0.
b. Effects of ambient temperature on motor temperature rise are linearly interpolated from 81.1 °F (de-rating factor = 1.0) to 104 °F (de-rating factor = 0.8727).
c. All motor operating parameters such as voltage and phase voltage balance are within normal ranges as specified in NEMA MG 1.

Maximum Motor Shaft Load[e] (bhp)						
Motor Nameplate (hp)	Ambient Temperature[a, b, c] (deg F)					
	81.1	85	90	95	100	104[d]
30	30.0	29.3	28.5	27.7	26.8	26.2
40	40.0	39.1	38.0	36.9	35.8	34.9
50	50.0	48.9	47.5	46.1	44.7	43.6
60	60.0	58.7	57.0	55.4	53.7	52.4
75	75.0	73.4	71.3	69.2	67.1	65.5
100	100	97.8	95.1	92.3	89.5	87.3
125	125	122	119	115	112	109
150	150	147	143	138	134	131
200	200	196	190	185	179	175
250	250	245	238	231	224	218
300	300	293	285	277	268	262
350	350	342	333	323	313	305
500	500	489	475	461	447	436
450	450	440	428	415	403	393
500	500	489	475	461	447	436

Notes:

a. Select motor based on 104 degrees F ambient temperature unless motor is in a moving air stream when operating.

b. Document selection of an ambient temperature lower than 90 degrees F.

c. Do not extrapolate to ambient temperatures below 81.1 or above 104 degrees F. If the ambient temperature is outside the 81.1 °F to 104 °F range, refer to NEMA MG 1 and/or the motor manufacturer for guidance.

d. If ambient temperature exceeds 104 degrees F, select motor with greater nameplate hp rating in accordance with NEMA MG 1.

e. Motor selection criteria developed from temperature rise considerations in NEMA MG 1-2003, clauses 12.43, 12.51.2, and 14.4.

E. For motors used with PWM adjustable frequency AC controllers provide motors that comply with Part 31 of NEMA MG1. For motors used with six-step adjustable frequency controllers provide motors that comply with either Part 30 or Part 31 of NEMA MG1.

F. Refer to LANL Construction Specification Section 16225 – *Induction Motors* for materials and installation requirements.

6.0 GROUNDING

6.1 Enclosure and Equipment Grounding

A. Install a 600 volt insulated (green) equipment ground conductor in each branch circuit raceway.[85]

B. Install a 600 volt insulated (green) equipment ground conductor in each raceway for line voltage control wiring and non-power-limited wiring systems. Size equipment-grounding conductors as required in the NEC.

C. An equipment grounding conductor is not required in raceways for power limited alarm and telecommunications wiring systems; however, metallic raceways must be electrically continuous as required by the NEC.[86]

D. Use materials and installation methods described in LANL Construction Specification Section 16060, *Grounding and Bonding*.

6.2 Isolated Grounding System

A. In addition to the equipment-grounding conductor, install a dedicated 600-volt insulated isolated grounding conductor with each isolated ground branch circuit.[87] *The purpose of isolated grounding systems is to reduce common-mode noise in circuits serving sensitive electronic equipment.*

1. Use green insulation with a yellow stripe.
2. Size equipment-grounding conductors as required in the NEC for equipment grounding conductors.
3. Connect the isolated ground conductors to the isolated ground bars in panelboards and to the isolated ground terminals at receptacles and equipment.

B. Use materials and installation methods described in LANL Construction Specification Section 16060, *Grounding and Bonding*.

6.3 Signal Reference Grid

A. Install a signal reference grid (SRG) for computer room raised floor areas.[88] Refer to IEEE Std. 1100, *Powering and Grounding Electronic Equipment* for additional design guidance.

B. Use one or a combination of the following systems:

---

85 Installation of an insulated equipment-grounding conductor is recommended practice in clauses 8.4.5.3 and 8.5.3 of IEEE Std 1100-1999. Clause 2.2.3 of IEEE Std 142-1991 indicates that the use of a metal raceway as a grounding conductor supplemented by an equipment grounding conductor achieves both minimum ground fault impedance and minimum shock hazard voltage.

86 Refer to NEC Section 300.10.

87 Recommended practice for isolated ground systems in IEEE 1100-1999 paragraph 8.5.3.2.

88 Recommended practice for equipment within a contiguous area in IEEE 1100-1999 paragraph 8.5.4.

1. Pre-fabricated grid of flat copper strips on 2 feet centers with all crossover connections factory welded. Bond every sixth raised floor pedestal to the SRG using 6 AWG grounding conductor.[89]
2. Raised floor pedestal system with bolted down metal horizontal stringers.
3. 2 ft X 2 ft grid of bare 6 AWG conductors clamped to raised floor pedestals.

C. Bond structural steel columns, pipes, conduits, and ducts, etc. passing through the SRG to the SRG using No. 6 AWG grounding conductor.

D. Bond computer equipment, power panels, and computer distribution units to the SRG using low impedance risers (LIRs).

1. Install LIRs made of 2 inch wide, 26-gauge copper strips or 1 inch wide flexible braided copper straps.
2. Do not connect any LIR to the SRG conductor at the outside edge of the SRG.
3. Keep the LIRs as short as possible.
4. If a LIR exceeds 24 inches, install two parallel LIRs connected to opposite corners of the equipment. Make the second LIR 20 percent to 40 percent longer than the first.

E. Use materials and installation methods described in LANL Construction Specification Section 16060, *Grounding and Bonding*.

6.4 Control of Static Electricity

A. Control static electricity to prevent fire and explosion.[90] This requirement applies to all locations where there is the potential to create an ignitable mixture and electrostatic energy can be created, accumulated, and discharged with energy exceeding the minimum ignition energy of the mixture; such locations include:

- Bottle racks
- Flammable storage cabinets
- Drum storage/dispensing racks
- Loading docks and other transfer points
- Processing equipment
- Storage tanks.

B. Use methods and materials described in NFPA 77, *Recommended Practice on Static Electricity* and in LANL Construction Specification Section 16060, *Grounding and Bonding*.

7.0 INTERIOR LIGHTING

7.1 Design

A. Design interior lighting systems in accordance with the current versions of following standards:

---

89 Recommended practice for signal reference grids in IEEE 1100-1999 paragraph 8.5.4.
90 Refer to NFPA 77.

1. IESNA RP-1, *Office Lighting* (ANSI).
2. IESNA RP-5, *Daylighting*.
3. IESNA RP-7, *Industrial Facilities* (ANSI).
4. IESNA G-1, *Security Lighting for People, Property, and Public Spaces*
5. IESNA *Lighting Handbook*.
6. ASHRAE/IESNA Standard 90.1, *Energy Standard for Buildings except Low-Rise Residential Buildings*.

B. To assure quality of the visual environment and efficient illumination, coordinate interior finishes with the architect or interior designer to obtain the initial surface reflectance recommended in the IESNA *Lighting Handbook*:

1. Office environments (offices, conference rooms, laboratories, etc.):[91]
   - Ceilings: 80% or more
   - Walls: 50-70%
   - Floors: 20-40%
   - Furniture: 25-45%
2. Industrial environments (Shops, process spaces, warehouses, etc.):[92]
   - Ceilings: 80% or more
   - Walls: 40-60%
   - Floors: not less than 20%
   - Furniture and equipment: 25-45%

C. Integrate lighting systems with daylighting systems to increase occupant satisfaction and conserve energy. Consider daylighting effects in any space where daylight is admitted, even if it is not exploited as a light source, in order to avoid problems with glare and damage to materials.[93]

D. Perform lighting calculations using procedures[94] outlined in the IESNA *Lighting Handbook*. Lighting calculations for each interior space shall include the following:

1. IESNA illuminance category selection (horizontal and vertical) and the underlying logic for selection (*e.g. recommended value in the IESNA Lighting Design Guide*).[95]
2. Design illuminance and logic for any departure from the recommenced values in the IESNA Lighting Design Guide.[95]

---

91 Recommended practice for office lighting from Figure 11-1 in the IESNA *Lighting Handbook*, Ninth Edition.
92 Recommended practice for industrial lighting from Figure 19-7 in the IESNA *Lighting Handbook*, Ninth Edition.
93 Refer to Chapter 8 in the IESNA *Lighting Handbook*, Ninth Edition.
94 Refer to Chapter 9 in the IESNA *Lighting Handbook*, Ninth Edition.
95 Refer to Chapter 10 in the IESNA *Lighting Handbook*, Ninth Edition.

3. Light loss factors and the underlying logic for their selection.[94] Use a lamp dirt depreciation factor (LDD) of 0.89 for offices, laboratories, and similar environments with modern HVAC systems and no activities that introduce unusual or abnormal dirt conditions.[96]
4. Calculated average initial and maintained illuminance based on the installed system. Calculated average "maintained" illuminance for the installed system shall be between –10 and +10 percent of the IESNA recommended illuminance.[97]

E. Satisfy the criteria rated "very important" to a high quality visual environment presented in the IESNA Lighting Design Guide.[95] *Consider the other criteria rated that contribute to a high quality visual environment presented in the IESNA Lighting Design Guide.*

F. Perform calculations[98] to show that the installed interior lighting power does not exceed the "interior lighting power allowance" developed in accordance with ASHRAE/IESNA Standard 90.1.[99]

1. Contracted design organization shall certify that the lighting system complies with the requirements of ASHRAE/IESNA Standard 90.1.[100]
2. Certification shall bear the seal and signature of the professional engineer in responsible charge of the lighting system design.[101]

7.2 Luminaires and Lamps

A. Coordinate selection of luminaires with user's functional needs, visual tasks to be performed, the type of equipment that will be used (e.g. computer terminals, etc.), architectural finish materials, and the environment in which the luminaires will be operating.

B. Select luminaires and lamps to facilitate cost-effective maintenance of lamps, ballasts, and luminaire parts such as reflectors and lenses. Use long-life lamps, remote ballasts, lowering devices, etc. as required by the installation location.[102]

C. Minimize the number of lamp and ballast types on each project.[103]

D. Use lamps that pass the EPA *Toxicity Characteristic Leachate Procedure* (TCLP) test for hazardous waste determination.[104]

---

96 Refer to "Field Study of Luminaire Dirt Depreciation" by R. Levin, W. Brackett, J. Burke, and N. Frank published in Journal of the Illuminating Engineering Society, Vol. 31, No. 2, summer 2002.
97 Recommended practice in Chapter 9 of the IESNA *Lighting Handbook*, Ninth Edition.
98 Refer to Section 4.3 in ASHRAE/IESNA Standard 90.1-2001.
99 Refer to Section 9 in ASHRAE/IESNA Standard 90.1-2001.
100 Certification by the design agency will be accepted instead of a detailed review of the compliance documents required in Section 4.3 in ASHRAE/IESNA Standard 90.1-2001.
101 Required by New Mexico Engineering and Surveying Practice Act (Chapter 61, Article 23 NMSA 1978).
102 Refer to Chapter 28 in the IESNA *Lighting Handbook*, Ninth Edition.
103 Minimizing the number of lamp and ballast types reduces the costs and inventory required to maintain a building lighting system.
104 The Toxicity Characteristic Leaching Procedure (TCLP) is designed to simulate the leaching a waste will undergo if disposed in a sanitary landfill. Refer to EPA SW-846, "Test Methods for Evaluating Solid Waste (Physical/Chemical Methods)," Chapter 7, "Toxicity Characteristic Leaching Procedure," page SEVEN-13.

E. For fluorescent general lighting in interior spaces, use 120V or 277V luminaires with electronic energy-saving ballasts, and energy-efficient lamps.

1. For T-8 fluorescent lamps use NRTL listed electronic energy-saving ballasts. Use "programmed start" electronic ballasts for fluorescent lamps when occupancy sensors control the system.

2. For new systems use T-8 fluorescent lamps with the following salient features:
   - 3500 ºK color temperature.
   - Color rendering index (CRI) of 75 or better.

3. For re-lamping of existing luminaires containing 48-inch T-12 fluorescent lamps, use T-12 lamps with the following salient features:
   - Spot re-lamping: 4100 ºK color temperature to match existing "lite-white" lamps.
   - Group re-lamping: 3500 ºK color temperature to match T-8 lamps.
   - Color rendering index (CRI) of 70 or better.

F. For accent and special purpose lighting in interior spaces use 120V or 277V fluorescent luminaires with UL listed energy saving, high power factor ballasts and compact lamps with 2700 ºK, CRI-80 color characteristic.

G. Select lamp/ballast combinations that will start and operate properly in the ambient environment.

H. Select luminaires for general illumination of office environments (e.g. private offices, open plan offices, conference rooms, and laboratories) using the following criteria and the criteria in Chapter 11 of the IESNA *Lighting Handbook*:

1. Where the ceiling height is less than 9'-0" use recessed fluorescent troffers that have a minimum visual comfort probability (VCP) of 70% and a further minimum VCP of 80% where video display terminals are used. As an alternative to VCP criteria, luminaires with an average luminance not exceeding the "preferred" values in Figure 11-19 in the IESNA *Lighting Handbook* may be used in VDT environments.[105]

2. When the ceiling height in office or laboratory environments is 9'-0" or higher, use indirect or direct/indirect distribution, pendant or cable suspended fluorescent luminaires unless they will interfere with equipment to be installed in the space. Suspend luminaires not less than 18 inches below the ceiling and the bottom of the luminaires not less than 7'-6" above the finished floor. Design the lighting system to provide a maximum ceiling luminance of 850 cd/m^2 with 4:1 uniformity or better.[105]

I. Select luminaires for general illumination of industrial environments using the following criteria and the criteria in Chapter 19 of the IESNA *Lighting Handbook*:

1. Where luminaires will be mounted more than 25 ft above the floor use "high bay" pulse-start metal-halide[106] luminaires that shield the light source not less than 25 degrees from the horizontal (*preferably to 45 degrees*) and have a 10% to 30% upward component[107].

---

[105] Recommended office lighting practice in Chapter 11 of the IESNA *Lighting Handbook*, Ninth Edition.

[106] Pulse-start metal-halide technology provides significant operating and maintenance cost improvements over conventional probe-start metal halide lighting systems. Pulse-start metal halide lighting provides "white light" that is much more accepted by occupants than high-pressure sodium's "golden-white" light, with only slightly higher life cycle cost.

[107] Recommended industrial lighting practice in Chapter 19 of the IESNA *Lighting Handbook*, Ninth Edition.

Use lamps with a minimum color rendering index (CRI) of 65 [107] and a color temperature of approximately 4000 ºK. Provide supplemental instant-on lighting providing a minimum of 1 footcandle illuminance while HID lamps are starting or re-starting.[108]

2. Where luminaires will be mounted 25 ft or less above the floor use "low bay" pulse-start metal-halide[106] luminaires that have prismatic lens to control glare. Use lamps with a minimum color rendering index (CRI) of 65[107] and a color temperature of approximately 4000 ºK. Provide supplemental instant-on lighting providing a minimum of 1 footcandle illuminance while HID lamps are starting or re-starting.[108]

3. Where luminaires will be mounted 15 ft or less above the floor use fluorescent industrial luminaires that that shield the light source not less than 25 degrees from the horizontal perpendicular to the fixture and have a 10% to 30% upward component. Use T-8 lamps with a minimum color rendering index (CRI) of 75[107] and a color temperature of approximately 3500 ºK.

J. Space luminaires at approximately 0.65 times the maximum spacing to mounting height ratio to reduce the effects of a single lamp failure.[109]

K. In industrial environments circuit luminaires to minimize stroboscopic effects from HID and fluorescent light sources. Operate luminaires on alternate phases of the 3-phase power supply.[110]

L. Use materials and installation methods described in LANL Construction Specifications Section 16510 - Interior Lighting System.

7.3 Lighting Control

A. For all new buildings and renovation areas in existing buildings provide lighting controls that comply with the requirements in ASHRAE/IESNA Standard 90.1.[111]

B. For all lighting control device replacements in existing buildings, provide lighting controls that comply with the requirements in ASHRAE/IESNA Standard 90.1.[112]

C. Provide occupancy sensing switching in all spaces with ceiling high partitions including the following spaces:[113]

- Private offices
- Open offices
- Laboratories
- Conference rooms

[108] Illuminance level for safety from Table 29-2 in the IESNA *Lighting Handbook*, Ninth Edition. Pulse-start metal-halide lamps require 2 to 3 minutes to warm-up when initially started and 4 to 6 minutes to re-strike after a momentary power interruption.

[109] Refer to 5.2.3.1 in IESNA RP-7-01.

[110] Refer to 3.7 in IESNA RP-7-01.

[111] Requirements in Section 9.2.1 of ASHRAE/IESNA Standard 90.1-2001 are extended to all LANL buildings, including those smaller than 5000 sq. ft. Occupancy sensor controls make it economical to provide automatic lighting shut-off in the smallest buildings.

[112] Requirement in Section 4.1.2.2.5 of ASHRAE/IESNA Standard 90.1-2001.

[113] Occupancy sensor controls are adopted as the method for achieving the automatic lighting shutoff required in Section 9.2.1.1 of ASHRAE/IESNA Standard 90.1-2001.

- Computer rooms
- Break rooms
- File rooms
- Copy machine rooms
- Utility rooms
- Restrooms
- Storage rooms
- Corridors
- Lobbies

Exceptions to the above requirement are spaces where lighting is intended for 24-hour operation and spaces where an automatic shutoff would endanger the safety or security of the room or building occupant(s).

D. Adjust time-out settings for occupancy sensors to optimize the combination of energy saving, relamping cost, and customer satisfaction. The following optimal settings have been determined: [114]

- Classrooms, private offices, open offices, laboratories, and restrooms: longest time-out setting, but not more than 30 minutes.
- Break rooms, storage rooms, copy machine rooms: 5-minute time-out setting
- Conference rooms: 10-minute time-out setting
- Corridors, lobbies: 15-minute time-out setting

E. Provide combined ambient light and occupancy sensing switching or combined ambient light and time clock switching for spaces or zones that receive daylighting from exterior windows or skylights.[115] Use ambient light sensors hold off or reduce the electric lighting contribution when daylighting exceeds 80% of the design illuminance at the work area. Make measurements at desk height in the center of the room. *In a typical office with a design illuminance of 50 footcandles, the ambient light sensor should hold the lights off as long as the daylighting exceeds 40 footcandles.*

F. Dual-Level Control

1. Provide dual-level light switching in areas 100 square feet and larger.[116]
2. Coordinate manual controls with automatic controls so that the manual control can reduce connected lighting load by at least 50 percent in a reasonably uniform illumination pattern.[117] *In a typical room with three-lamp fluorescent luminaires, arrange circuiting so the occupancy sensor controls all three lamps and the wall switch, connected on the load side of the occupancy sensor, controls two lamps.*

[114] Optimum occupancy sensor time-out settings based on technical paper “The Effects of Changing Occupancy Sensor Time-out Setting on Energy Savings, Lamp Cycling, and Maintenance Costs,” Journal of the Illuminating Engineering Society, Vol 30, No. 2, pp 97-110.

[115] Integrating daylighting controls into the building lighting control will reduce electrical and cooling loads.

[116] Dual-level switching allows users to reduce energy consumption when performing less demanding visual tasks.

[117] Dual-level control allows users to set illuminance to match task requirements, thus conserving energy. Drawn from California Title 24.

3. Arrange luminaires and dual-level circuiting to correspond to daylight apertures. *In a typical sidelighting design with windows along one wall, it is best to place the luminaires in rows parallel to the window wall and circuit so the row nearest the window will be the first to dim or switch off followed by successive rows.*

G. In corridors provide un-switched "night lighting" luminaires at the entrance/exit to the corridor and at major corridor intersections. *Night lighting luminaires may also be part of the emergency lighting system described below.*

H. Use materials and installation methods described in LANL Construction Specification Section 16140 – *Wiring Devices*.

7.4 Installation

A. Coordinate luminaire layout with building structure, architectural ceiling grid, furniture and equipment layout, HVAC ducts and diffusers, piping, and sprinkler heads.

B. Connect each luminaire in suspended ceilings using a wiring method that will facilitate relocation of the luminaire to adjacent grid openings. Suitable wiring methods include:

1. 6-ft fixture whips.

2. Manufactured wiring system as described in the NEC.[118]

C. Install luminaires using materials and methods that will facilitate fixture replacement and maintenance.

D. Install interior lighting systems in accordance with the manufacturer's instructions, LANL Construction Specifications Section 16510, *Interior Lighting System*, and the following industry standards:

1. NECA/IESNA 500, *Recommended Practice for Installing Indoor Commercial Lighting Systems*.

2. NECA/IESNA 502, *Recommended Practice for Installing Industrial Lighting Systems*.

8.0 EXIT AND EMERGENCY LIGHTING

8.1 General

A. Provide emergency exit pathway lighting and indication of exits in accordance with requirements in the *National Electrical Code*,[119] the *International Building Code*,[120] and NFPA 101 *Life Safety Code*.[121]

---

[118] Refer to NEC Article 604.
[119] Refer to NEC Article 700.
[120] Refer to Sections 1006 and 1011 in the International Building Code.
[121] Refer to Chapter 7 in NFPA 101, *Life Safety Code*.

B. Design emergency egress lighting and exit marking systems using recommendations in the IESNA *Lighting Handbook*.[122]

1. Design emergency lighting system to provide a minimum illuminance at every point in each exit pathways of 1 footcandle[123] with a uniformity ratio not exceeding 40:1.

2. Design emergency lighting system to provide a minimum illuminance at each hazard location in each exit pathway of 5 footcandles. Hazard locations include stairways, elevation changes, intersections, abrupt changes in direction, and exits.

C. Perform lighting calculations using procedures[124] outlined in the IESNA *Lighting Handbook*.

8.2 Emergency Lighting Unit Equipment

A. Use emergency lighting unit equipment that is UL 924 listed and labeled for the intended use.

1. In finished spaces of new office and laboratory LANL facilities with fluorescent luminaires use emergency battery/inverter units with the self-test feature described below.[125]

2. For typical service and industrial spaces in LANL facilities use wall-mounted, receptacle-connected incandescent unit equipment with the self-test feature described below.[126] Install a dedicated receptacle adjacent to each emergency lighting unit.

3. Certain locations in special facilities may have environments or other conditions that require special emergency lighting unit equipment suitable for the application.[127] Review such applications with the Electrical Chapter POC.

B. Where commercially available, provide emergency lighting units that automatically perform a self-test of battery and lamps for not less than 30 seconds every 30 days and have a visual status indicator to indicate any failure.[128] *Some special spaces, such as laser laboratories, may require that only manual testing be performed.*

C. Connect emergency lighting unit equipment to the branch circuit serving normal lighting in the area and ahead of any local switches. In lighting panelboards clearly identify the branch circuits that serve unit emergency lighting equipment.[129]

---

[122] Refer to Chapter 29 in the IESNA *Lighting Handbook*, Ninth Edition.
[123] Refer to Figure 29-2 in the IESNA *Lighting Handbook*, Ninth Edition.
[124] Refer to Chapter 9 in the IESNA *Lighting Handbook*, Ninth Edition.
[125] Inverter ballast units improve the aesthetics of finished spaces compared to cord-connected wall-mounted incandescent unit equipment. Some authorities say that the diffuse illumination provided by ceiling fluorescent luminaires is more conducive to orderly evacuation.
[126] Emergency lighting equipment is standardized and cord-connected to facilitate maintenance.
[127] Examples of special applications include corrosive environments, contamination environments, or spaces (such as bio-safety labs) that must have a minimum of surfaces to clean. Architectural preference alone is inadequate reason to use other than standard wall-mounted unit emergency lighting equipment.
[128] Periodic testing of emergency lighting equipment is required in section 7.9.3 of NFPA 101, *Life Safety Code*, 2000 Edition. Automatic self-testing is permitted; this feature greatly reduces the time required to test and maintain the emergency lighting system. Monthly visual inspections are still required
[129] Required by section 700.12(F) in the NEC; re-stated for emphasis.

D. Use materials and installation methods described in LANL Construction Specifications Section 16530, *Emergency Lighting*.

8.3 LED Emergency Exit Signs

A. Use LED emergency exit signs that are UL924 listed and labeled for the intended use and meet EPA "Energy Star" standards.

B. Provide exit signs with green[130] LED lamps producing a minimum luminance of 8.6 cd/m^2.[131]

C. New and replacement emergency exit signs shall automatically perform a self-test of battery and lamps for not less than 30 seconds every 30 days[132]; a visual status indicator and an audible alarm shall indicate any failure. Units shall also tests that are manually initiated by a test button.

D. Connect emergency exit signs to the branch circuit serving normal lighting in the area and ahead of any local switches. In the lighting panelboards clearly identify the branch circuits that serve emergency exit signs.[133]

E. Use materials and installation methods described in LANL Construction Specifications Section 16530, *Emergency Lighting*.

8.4 Self-Luminous Exit Signs

A. Use self-luminous exit signs only in special circumstances such as the following:[134]

1. Hazardous areas as defined in the NEC.

2. Structures that do not have electrical power but require exit signs.

3. When existing self-luminous exit signs fail or reach the end of their rated life.[135]

B. Replace self-luminous exit signs with LED emergency exit signs when lighting systems are replaced or renovated in areas containing self-luminous exit signs.

C. Use materials and installation methods described in LANL Construction Specifications Section 16530, *Emergency Lighting*.

---

130 Green is the color that has been used for exit signs at LANL for many years; some authorities say that green exit signs are more visible than red.
131 Refer to Chapter 29 in the IESNA *Lighting Handbook*, Ninth Edition.
132 NFPA 101, paragraph 7.10.9.2 establishes testing requirements for internally illuminated exit signs.
133 Required by section 700.12(F) in the NEC.
134 Self-luminous exit signs contain radioactive tritium. Increasingly stringent accountability requirements and uncertainty of future disposal costs weigh against continued use of these devices at LANL. Using current procurement, operating, maintenance, and disposal costs, the 20-year life cycle cost of a LED emergency exit sign is about the same as that for a self-luminous exit sign.
135 ESM variance request on self-luminous exit sign replacements approved on 3/31/04.

9.0 EXTERIOR BUILDING LIGHTING

9.1 Selection

A. Provide building-mounted safety and security lighting for exterior doors, stairways, loading docks, and mechanical equipment yards, plus parking lots and pedestrian walkways located adjacent to the building.[136]

B. Perform lighting calculations using procedures outlined in the IESNA *Lighting Handbook.* Use point-by-point methods for exterior applications.[137]

C. Select and install exterior lighting systems following guidance in the IESNA *Lighting Handbook.*[138]

D. Minimize the number of lamp and ballast types. [103]

E. Use high-pressure sodium (HPS) luminaires with cut-off type distribution that complies with the State of New Mexico "Night Sky Protection Act" [139] which can be accessed at http://users2.ev1.net/~mmccants/eolc/nmlaw.html. *The International DarkSky Association "Lighting Code Handbook" provides useful guidance.*

F. Select, locate, and aim luminaires to minimize unintentional illumination of adjacent terrain and so that glares are not directed towards any guard station or roadway.[140]

G. Use materials and installation methods described in LANL Construction Specifications Sections 16510, *Interior Lighting System,* and 16520, *Exterior Lighting System*.

9.2 Control

A. Provide exterior building lighting controls that comply with the requirements in ASHRAE/IESNA Standard 90.1. [141]

B. Control exterior lighting to be on at dusk and off at dawn by means of photocells through HAND-OFF-AUTO selector switch and lighting contactor.

C. Use materials and installation methods described in LANL Construction Specifications Section 16520, *Exterior Lighting System*.

---

136 Refer to Chapter 21 in the IESNA *Lighting Handbook,* Ninth Edition.
137 Refer to Chapter 9 in the IESNA *Lighting Handbook*, Ninth Edition.
138 Refer to luminaire classification section in Chapter 21 of the IESNA *Lighting Handbook*, Ninth Edition.
139 The "Night Sky Protection Act" was passed by the 44th New Mexico State Legislature, 1st Session of 1999, Chapter 197, House Bill 39. Its purpose is to regulate outdoor lighting to preserve and enhance the state's dark sky while promoting safety, conserving energy, and preserving the environment for astronomy.
140 Refer to lighting trespass section in Chapter 21 of the IESNA *Lighting Handbook*, Ninth Edition.
141 Refer to section 9.2.1.2 in ASHRAE/IESNA Standard 90.1-2001.

9.3 Installation

Install exterior lighting systems in accordance with the manufacturer’s instructions, LANL Construction Specifications Section 16520, *Exterior Lighting System*, the NEC, and NECA/IESNA 501, *Recommended Practice for Installing Exterior Lighting Systems*.